LOW TEMPERATURE DEPOSITION OF SILICON BASED THIN FILMS BY SINGLE-WAFER HOT-WALL RAPID THERMAL CHEMICAL VAPOR DEPOSITION

Cross Reference to Related Applications

This application claims the benefit of and priority to the United States Provisional Application No. 60/408,709 filed September 5, 2002, entitled "Low Temperature Deposition of Silicon Based Thin Films by Single Wafer Hot-Wall Rapid Thermal Chemical Vapor Deposition", the disclosure of which is herein incorporated by reference in its entirety.

Field of the Invention

The present invention relates generally to systems and methods for processing of semiconductors. More specifically, the present invention relates to a system and method for deposition of silicon based films at low temperatures using single wafer hot-wall thermal chemical vapor deposition.

Background of the Invention

Low thermal budget processing of silicon-based dielectrics is becoming increasingly important in future IC device fabrication. For example, the self-aligned metal silicide process requires a low temperature deposition of silicon nitride sidewall spacers.

Conventional low pressure chemical vapor deposition (LPCVD) processes have been performed using a hot wall batch furnace with dichlorosilane. Such a system is comprised of a large cylinder in which up to 150 wafers can be loaded. The temperature is slowly ramped up to its setpoint before gases are introduced to initiate deposition. Typical cycle times for this technique are on the order of 6 hours. Silane is not commonly used in batch furnace processes due to the difficulty in achieving thickness uniformity control.

Alternatively, single-wafer rapid thermal chemical vapor deposition (RTCVD) techniques in a cold wall reactor have been used to rapidly deposit films under LPCVD conditions using silane as a precursor or reactant. These systems use lamp-based technology to heat the wafers and are sensitive in wafer temperature control to wafer backside emissivity. Dichlorosilane is not suitable for cold-wall system reactor due to condensation of NH_4Cl solid byproduct. Thus, both conventional techniques suffer from limitations, and improved systems and methods for deposition of silicon based films are highly desirable.

More recently, an improvement has been made using an RTCVD technique in a hot-wall reactor. This method is described in commonly assigned United States Application No. 10/106,677 filed March 25, 2002, entitled "System And Method For Improved Thin Dielectric Films" the disclosure of which is hereby incorporated by reference in its entirety. While this technique provides an advantage, the process is carried out at high temperatures generally up to approximately 900 °C. Lower temperatures are more desirable, and thus there remains a need for further developments in the industry.

Summary of the Invention

The present invention provides a single-wafer hot-wall RTCVD system and method capable of achieving high deposition rates, to deposit silicon nitride films or layers (Si_3N_4) using certain precursors or reactants at low temperatures of up to approximately 550°C. Despite such a high deposition rate, the resulting films produced by the present invention show unexpectedly beneficial thickness uniformity and step coverage properties.

In one embodiment a method of depositing a silicon based film on a wafer is provided characterized in that at least one silicon containing precursor and at least one chemical precursor are introduced into a hot-wall thermal chemical vapor deposition chamber housing a wafer, and wherein the precursors react to form a silicon based film on the wafer at a deposition rate of approximately 100Å/min. or greater.

In another embodiment, a method of depositing a silicon based film on a wafer in a hot-wall thermal chemical vapor deposition chamber is provided wherein the wafer is heated to a temperature of up to approximately 550 °C; with the pressure in the chamber being in the range of approximately 10 to 500 Torr. At least one silicon

containing precursor is conveyed to the chamber and is comprised of any one of, or combination of SiH_4, $SiCl_2H_2$, Si_2H_6, Si_2Cl_6, $SiCl_3H$, or $SiCl_4$, and at least one nitrogen containing precursor comprised of any one of or combination of NH_3, alkyl amine, hydrazine, alkylhydrazine, alkyl amide, alkyl imide or atomic nitrogen is conveyed to the chamber. The precursors react and deposit a silicon based film on the wafer at a deposition rate of 1000 Å/minute and greater.

Brief Description of the Drawings

The invention will be described in detail in the following description of preferred embodiments with reference to the following figures wherein:

Figure 1 is a simplified cross sectional schematic view of one example of a rapid thermal chemical vapor deposition system suitable for carrying out the present invention according to one embodiment.

Figure 2 illustrates a graph of thickness passive data collection or repeatability test (PDC) results for wafers fabricated according to one embodiment of the present invention;

Figure 3 illustrates a graph of refractive index PDC results for wafers fabricated according to one embodiment of the present invention;

Figure 4 shows the effect of Si_2H_6 and NH_3 on the deposition rate and refractive index at constant pressure, temperature and nitrogen gas flow rate; and

Figure 5 is a cross section of a SEM image showing the step coverage achieved with the system and method of the present invention.

Detailed Description Of The Invention

The present invention provides a system and method for deposition of silicon based films at low temperatures using a hot-wall, single wafer, rapid thermal chemical vapor deposition (RTCVD) system.

Shown in Fig. 1 is a simplified schematic of the single-wafer hot-wall rapid thermal chemical vapor deposition (RTCVD) system or reactor which may be used to carry out the method of the present invention. While one example of an RTCVD system is shown in FIG. 1, other RTCVD systems may be used. In general, the exemplary hot-wall RTP reactor 10 comprises a chamber 14 into which a single substrate 20 is loaded. The wall of the chamber 14 is preferably made of quartz. A plurality of heating elements 12 are provided adjacent to the upper end of the chamber

14. Suitable heating elements include resistive heating elements coupled with a power source controlled by a computer (not shown). In one embodiment an isothermal plate 13, preferably made of quartz, is disposed inside and adjacent to the upper end of the chamber 14. Alternatively, the isothermal plate 13 may be positioned outside of the chamber 14, such as adjacent to the heating elements 12. The heating elements 12 and isothermal plate 13 serve as heating sources for the use of the RTP reactor 10. The isothermal plate 13 can be placed in the chamber 14 or on the top of chamber 14. The isothermal plate 13 receives heat rays radiated from the heating elements 12 and radiates secondary heat rays into the chamber 14. The isothermal plate 13 can produce more uniform thermal distribution on the surface of the substrate 20 and is thus preferred but is not required.

The hot-wall RTP reactor 10 further comprises one or more insulation sidewalls 24 adjacent to the sidewall of chamber 14. Heating means (not shown) may be provided between the insulation sidewalls 24 and the sidewall of the chamber 14 to heat the sidewall of the chamber 14 to achieve a more accurate control over the temperature within the chamber 14.

The single substrate 20 is supported by a platform 22 which is coupled with an elevator 26 for moving the substrate 20 into and out of the chamber 14. One or more gas inlets 16 are disposed at the sidewall of the chamber 14 and connected to one or more gas manifolds (not shown) which convey a gas or a mixture of gases into the chamber 14. The gas concentration and flow rates through each of the gas inlets 16 are selected to produce reactant gas flows and concentration that optimize processing uniformity. An exhaust line 18 is provided at the sidewall of the chamber 14 opposite the gas inlets 16 and connected to a pump 28 for exhausting the chamber 14. While one specific hot-wall RTP reactor has been described, the invention is not limited to this specific design, and other hot-wall RTP reactors may be employed within the teaching of the present invention.

In one embodiment, the present invention provides a method of depositing a silicon based film on a wafer wherein at least one silicon containing precursor and at least one chemical precursor (sometimes collectively referred to as "process gases") are introduced into a hot-wall thermal CVD chamber housing a wafer. The wafer is heated to a wafer temperature of up to approximately 550 °C. The process gases mix and react to form a silicon based film on the wafer.

More specifically, in one example the method is carried out as follows. A wafer is loaded into a lower chamber (not shown) of reactor 10. The wafer is then pushed under vacuum into chamber 14 as shown in Fig. 1, via elevator 26. Energy is applied to the heating elements to heat the wafer. Process gases are then introduced, and the film is deposited on the silicon wafer until a desired thickness has been achieved. After deposition is complete, the wafer is lowered for cooling.

Of particular advantage, the present invention provides high deposition rates at relatively low temperatures. More specifically, the present invention provides for heating the wafer to a temperature of up to approximately 550°C. In another embodiment, the wafer temperature is in the range of approximately 400 °C to 550 °C. In yet another embodiment the wafer temperature is in the range of approximately 400 °C to 525 °C. The method of the present invention is carried out at a pressure in the range of approximately 10 to 500 Torr, more preferably between 100 and 200 Torr.

Suitable silicon source precursors include both chlorine- and hydride-based silicon sources, such as but not limited to SiH_4, $SiCl_2H_2$, Si_2H_6, Si_2Cl_6, $SiCl_3H$, and $SiCl_4$. In one embodiment of the present invention, the flow rate of such suitable silicon source precursor is conveyed to the chamber is in the range of 10 sccm to 500 sccm.

The present invention includes in particular the use of Si_2H_6 as the precursor for depositing silicon based films such as silicon nitride, silicon oxide, silicon oxynitride, polysilicon, and germanium doped polysilicon.

The silicon source precursor may be conveyed with or without one or more inert gases. Examples of suitable inert gases include, but are not limited to nitrogen, argon, helium, and the like. In one embodiment of the invention, inert gas is conveyed to the chamber at a flow rate in the range of 0 to 20,000 sccm.

In one embodiment the chemical precursor is a nitrogen source. Suitable nitrogen source precursors include any one, or combination, of NH_3, alkyl amine, hydrazine, alkylhydrazine, alkyl amide, alkyl imide, and atomic nitrogen. In one embodiment, such nitrogen source precursors are conveyed to the chamber at a flow rate in the range of 10 to 10,000 sccm.

An oxidant may also be employed. Suitable oxidant sources include any one, or combination, of Ozone, O_2, NO N_2O, H_2O, H_2O_2, and atomic oxygen.

Unlike that found using metal-organic precursors in the prior art, such as bis(t-butylamino)silane (BTBAS), the resulting films prepared by the method of the present invention have no carbon contamination.

The present invention may be employed to fabricate a number of semiconductor device structure, such as, but not limited to: sidewall spacers (Si_3N_4, SiO_2); gate and capacitor dielectrics (Si_3N_4, SiOxNy, ON stack, ONO stack); gate electrodes (polysilicon, Poly Si-Ge); and optical coatings (SiOxNy).

Experimental

A number of experiments were preformed. The following experimental results are provided for purposes of illustration only, are not intended to limit the invention in any way. Deposition rates of approximately 1000 Å/min were obtained with uniformity < 2% 1σ. The refractive index (RI) was also found to be controllable to provide a RI of 2.007 ± 0.003. Listed below in Table 1 are the process parameters and results of the high deposition rate.

Table 1. Si_2H_6 process parameters for the high deposition rate CVD of Si_3N_4.

Setpoint	Pump-down	Initialize	Deposition	Cooling	Pump-down
Process time [s]	120	120	Variable	120	60
Si_2H_6 [sccm]	0	0	320	0	0
NH_3 [sccm]	0	6075	6075	6705	0
N_2 [sccm]	0	4675	4675	4675	0
Pressure Setting [Torr]	0.010	130	130	130	0.010
Elevator Position	Cooling	Process	Process	Cooling	Cooling
Rotator Speed [rpm]	0	6	6	6	0
Wafer Temp. [°C]	N/A	550	550	550	N/A

In addition, a medium deposition rate process of approximately 500Å/min has been created. The parameters for this process are shown in Table 2. A twenty-four wafer PDC was performed using this process and the results are presented in Fig. 2 and Fig. 3.

Table 2. Si_2H_6 process parameters for the medium deposition rate CVD of Si_3N_4.

Setpoint	Pump-down	Initialize	Deposition	Cooling	Pump-down
Process time [s]	120	120	Variable	120	60
Si_2H_6 [sccm]	0	0	96	0	0
NH_3 [sccm]	0	5250	5250	5250	0
N_2 [sccm]	0	5005	5000	5000	0
Pressure Setting [Torr]	0.010	100	100	100	0.010
Elevator Position	Cooling	Process	Process	Cooling	Cooling
Rotator Speed [rpm]	0	6	6	6	0
Wafer Temp.[°C]	N/A	550	550	550	N/A

The data from the PDC has been analyzed and is presented below in Table 3. Excellent repeatability was achieved in both thickness and RI.

Table 3. Processed data from PDC.

	Thickness (Å)	Thickness 1σ (%)	RI Mean	RI 1σ (%)
Average	499.31	1.62	2.006	0.675
Max	512.18	1.71	2.014	0.926
Min	492.64	1.48	2.003	0.608
St Dev.	4.94	0.06	0.002	0.064
WTW Unif. (1σ)	0.99		0.120	

Several experiments were performed to determine the effects of the individual parameters on the results of the process. These relationships are summarized below in Table 4 and are illustrated in Fig. 4. The Si_2H_6 flow was found to be the largest contributor to the deposition rate. This was followed by NH_3 flow. The effects of both variables have been plotted at a constant N_2 flow of 5.0 slm, a pressure of 100 Torr at a wafer temperature of 550°C.

Table 4. Effects of process variables on the process performance. The arrows next to the results represent either an increase (↑) or decrease (↓) as the primary variable is increased. Negligible effects are denoted with an 'X'.

	Response		
Variable	**Dep. Rate**	**RI**	**Unif.**
↑ Si_2H_6	↑↑	↑	X
↑ NH_3	↓	↓	↓
↑ N_2		X	↓
↑ Pressure	↑	↓	X
↑ Elevator	↑	↑	↑ & ↓

Fig. 5 shows the excellent step coverage achieved by the system and method of the present invention. The film shown in the SEM image is silicon nitride deposited with a Si_2H_6 precursor at a temperature of about 550°C and at a deposition rate of about 500Å/min.

Exemplary embodiments have been described with reference to specific configurations. The foregoing description of specific embodiments and examples of the invention have been presented for the purpose of illustration and description, and although the invention has been illustrated by certain of the preceding examples, it is not to be construed as being limited thereby.